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SURFACTANTS IN THE WAKE OF A SURFACE SHIP AND THEIR INFLUENCE ON AMBIENT WAVES

Final Technical Report for ONR Grant No. N00014-89-J-1354

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Introduction

This document represents the Final Technical Report for ONR Grant No. N00014–89–J–1354, "Surfactants in the Wake of a Surface Ship and Their Influence on Ambient Waves" — period of performance November 1, 1988 through April 30, 1991. Since this grant was a direct replacement for ONR Contract No. N00167–88–K–0052, "Bubble Transport of Surface Active Organic Compounds in Seawater" — period of performance April 1, 1988 through March 31, 1989 — accomplishments under this latter contract are also reported here.

The research conducted under these auspices was greatly enhanced by our concurrent participation in the Surface Ship Wake Consortium having membership (aside from ours) from the University of Michigan, the Massachusetts Institute of Technology, the U.S. Naval Research Laboratory and the David Taylor Research Center. The research was also enhanced by our collaborative participation in the Surface Ship Wake Detection Program.

Technical Objectives and Issues

It has been established through a series of field experiments that sufficient amounts of surface–active organic materials accumulate in the wake of a surface ship to cause significant reductions in the surface tension across certain portions of the wake vis–a–vis the ambient surface tension of seawater. Such accumulations of surfactant material are known to strongly damp ocean waves of less than 15 to 20 cm in wavelength. Hence, it

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seems probable that the observed accumulations of surfactant materials play a critical role in the formation and persistence of the long, narrow, "dead water" region occurring in the wake of a surface ship.

Our objective was to synthesize a model that describes the distribution of surfactants in the wake of a surface ship and to determine the effects of this distribution on the ambient wave field. The major components of the model were to encompass sources of surfactant accumulation, causes of surfactant dissipation, and wave regeneration due to wind. A primary source of surfactant accumulation is now thought to be bubble scavenging of surfactant materials from the water column. As input to the model, we conducted experimental studies to determine the relationships among bubble size, bubble production rate, and volumetric concentrations and types of surface–active organic compounds in seawater to the rates at which these compounds were scavenged from the water column and deposited on the surface by the bubbles.

Technical Accomplishments

We have synthesized a model that describes the interaction between the wake produced by a surface ship and the ambient wave field. The model includes wave damping by surfactants and turbulence and wave regeneration by wind and nonlinear energy transfer. This model has been applied to measurements and observations made during the West Coast Ship Wake Observability Exercises in 1989. Our results (Peltzer, et al, 1990) which are in good quantitative agreement with wake measurements, indicate that surfactant films play an important role in the formation and persistence of the centerline wake region and that this role is probably dominant in the far wake. In the near and intermediate wake regions, other influences on wave energy cannot be neglected — especially at L-band where it is necessary to invoke wave damping by turbulence to explain the SAR observations.

A significant source of surfactant accumulation in the centerline wake region is

bubble scavenging of naturally occurring surfactants from the water column. We have completed our planned set of experiments to characterize this process using four types of C14 labeled lipids (stearic acid, oleic acid, triolein and cholesterol). All four materials were subjected to scavenging at various air flow rates using bubbles having a mean diameter of 203 μm. We have found from these studies (Skop et al, 1990) that the scavenging rate for each material is proportional to the bulk water concentration of the material and that the constant of proportionality depends on the specific material and the air flow rate. We have found that oleic acid is scavenged more rapidly than stearic acid, which is scavenged more rapidly than triolein. The latter material is similarly scavenged more rapidly than cholesterol. This finding indicates a strong dependence of the scavenging process on the underlying chemical polarity and/or stereochemical properties of the materials being scavenged. Using stearic and oleic acids, we have also completed scavenging experiments with bubbles having mean diameters of 308 μm and 743 μm. Our analyses (Viechnicki, 1991) indicate that the underlying processes observed with 203 μm mean diameter bubbles can be scaled by bubble surface area. This finding is a direct indication that the scavenging process can be described by saturation–limited diffusion dynamics.

In connection with our scavenging experiments, the rate of transport of surfactants to the water surface by mixing currents has also been examined (Brown et al, 1991). Our results here show that while currents are far less efficient than the bubble scavenging process in bringing surfactants to the surface, there is a distinct correlation between current and bubble–mediated transport. Namely, oleic acid is transported more rapidly than stearic acid, which is transported more rapidly than triolein. The latter material is similarly transported more rapidly than cholesterol.

In connection with our scavenging experiments, we have studied the transfer of surface-active organic compounds by bursting bubbles to an altitude of 10 cm above the still water level of our test tank (Tseng et al, 1991). We have found that the amount of surfactant transported to the 10 cm altitude is linearly proportional to the amount of

surfactant brought to the water surface by bubble scavenging. The constant of proportionality is independent of the type of surfactant but does depend on the air flow rate (increasing with increasing air flow rate) and bubble size (increasing with decreasing bubble size).

Significance of Accomplishments

Our model for predicting wave damping and regeneration in the centerline wake region of a surface ship has provided good quantitative agreement with measurements made during the West Coast Ship Wake Observability Exercises. These results indicate that we have isolated the most important factors governing the persistence of the centerline wake region. However, several terms in the model are understood only very approximately and a host of questions remain to be answered before a complete physical description of this region can be formulated. Among these questions are the detailed processes of wave regeneration by wind and nonlinear energy transfer and the wake flow and turbulence induced by rising and bursting bubble plumes.

Our results on bubble scavenging of surfactants as a source of surfactant accumulation in the centerline wake region have shown that this is a viable process.. Further, we have demonstrated that radio–labeling techniques can be used to obtain quantitative measurements of the scavenging process. We have found that this process is critically dependent on the underlying chemical polarity and/or stereochemical properties of the material being scavenged. This finding indicates that, for a multi–component surfactant background such as that found in the ocean, differential scavenging controls which materials are brought to the surface. Our results to date also indicate that the scavenging process can be described by saturation–limited diffusion dynamics. This finding will allow the construction of a firm theoretical base of the scavenging process.

We have also demonstrated that our radio–labeling technique can be used to examine the sea–to–air transfer of surfactant materials by bursting bubbles (or, more

generally, the bubble bursting process) with unprecedented accuracy.

Publications

The following publications resulted, in whole or in part, from the research conducted under ONR Grant No. N00014–89–J–1354 and ONR Contract No. N00167–88–K–0052.

Refereed Journals

R.A. Skop, S.E. Ramberg and J.W. Brown (1989). "Adaptation of a Digital Nuclear Imaging Technique for the Study of Bubble Scavenging of Surface–Active Organic Materials in Seawater," Technical Note, Experiments in Fluids, V. 7, pp. 429–431.

R.A. Skop, W.G. Lindsley, and J.W. Brown (1991). "Radiotracer Studies of Surfactant Transport to the Sea–Air Interface by Submillimeter–Size Bubbles," Experiments in Fluids, V. 10, pp. 251–256.

W.G. Lindsley, R.A. Skop and J.W. Brown (1991). "Surface Pressure and Wave–Damping Effects of Surface Active Organic Compounds on Seawater," Ocean Engineering, in press.

R. Tseng, J.T. Viechnicki, R.A. Skop and J.W. Brown (1991). "Sea-to-Air Transfer of Surface–Active Organic Compounds by Bursting Bubbles", Journal of Geophysical Research — Oceans, in press.

J.W. Brown, R.A. Skop, J.T. Viechnicki and R. Tseng (1991). "Transport of Surface–Active Organic Materials from Seawater to the Air–Water Interface by an Ascending Current Field," Fluid Dynamics Research, in review.

Conference Proceedings

R.D. Peltzer, J.H. Milgram, R.A. Skop, J.A.C. Kaiser, O.M. Griffin and W.R. Barger (1990). "Hydrodynamics of Ship Wake Surfactant Films," Proceedings of the 18th Symposium on Naval Hydrodynamics, Ann Arbor, MI.

Technical Reports

R.A. Skop, J.W. Brown and W.G. Lindsley (1989). "Bubble Transport of Surface–Active Organic Compounds in Seawater: Initial Measurements and Results," RSMAS Technical Report 89–3.

Theses and Dissertations

W.G. Lindsley (1989). "Surface Pressure and Bubble Transport of Surface–Active Compounds in Seawater," M.S. Thesis, University of Miami, Miami, FL.

J.T. Viechnicki (1991). "Bubble and Current Transport of Natural Surfactants in Seawater," M.S. Thesis, University of Miami, Miami, FL.

Participants

The following investigators participated in the research conducted under ONR Grant No. N00014–89–J–1354 and ONR Contract No. N00167–88–K–0052.

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John W. Brown, Co–Principal Investigator, Research Associate Professor, Division of Applied Marine Physics.

Ruo–Shan Tseng, Rosenstiel Post–Doctoral Fellow, Division of Applied Marine Physics.

William G. Lindsley, Graduate Assistant, Division of Applied Marine Physics (MS obtained June 1989).

John T. Viechnicki, Graduate Assistant, Division of Applied Marine Physics, (MS obtained May 1991).